2011

Microperforated Materials as Duct Liners: Local Reaction vs. Extended Reaction

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Microperforated Materials as Duct Liners: Local Reaction *vs*. Extended Reaction

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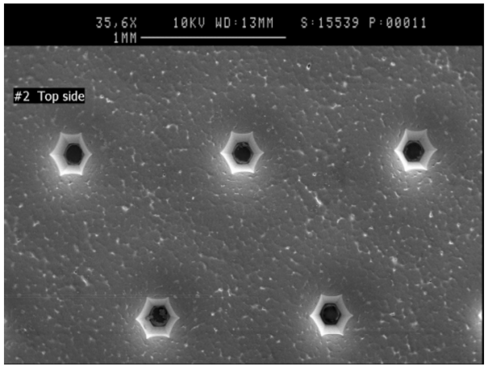
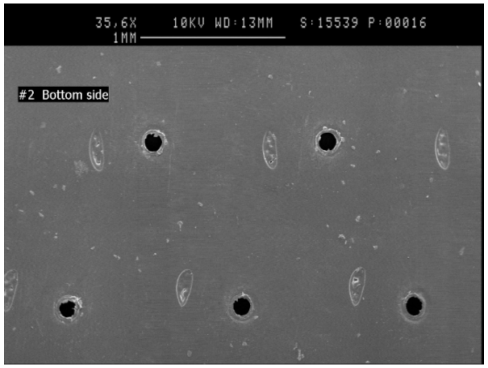
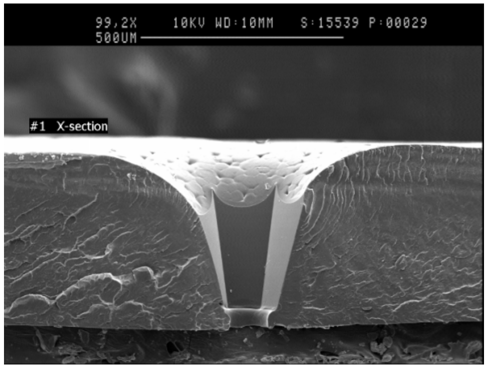
Introduction

- Question: Can microperforated materials (MPPs) be used to create duct linings that produce attenuation comparable with that of fibrous duct linings.
  - MPP silencers only required an air-cavity in the backing space.
  - No problems with fiber erosion
  - More easily cleanable than fibrous linings
  - Both the local and extended reaction treatments are considered

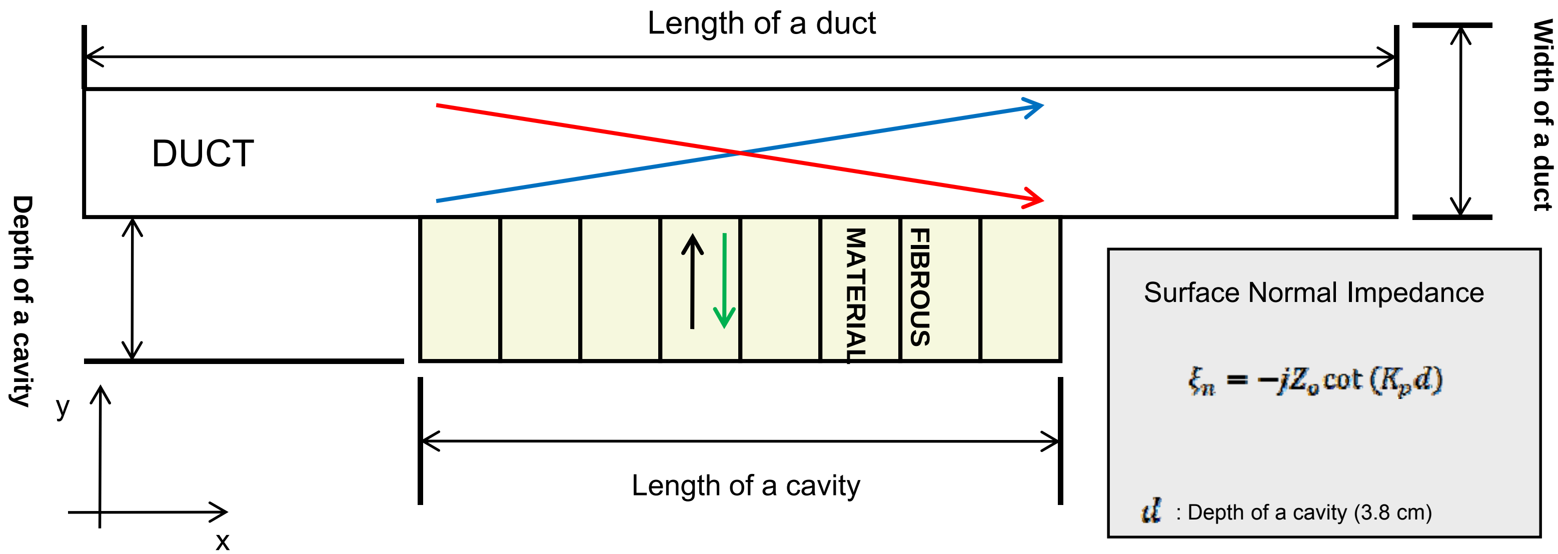






Analytical model approaches

- Configuration of local reaction treatment
- Use Miki model for fibrous media to represent glass fiber [1]



Analytical model approaches

- Basic equations and solution methods

Basic equation

$$F(W) = W\tan(W) - \frac{jKL}{\xi_n}$$

L : Width of a duct

$$K_y = \frac{W}{L}$$

Solutions

$$K_x L = \sqrt{(KL)^2 - (W)^2}$$

$$K_x = \beta - j\alpha$$

Complex wave numbers in x-direction

$$\alpha = -\mathrm{Im}\{K_x\}$$

Imaginary part of wave number

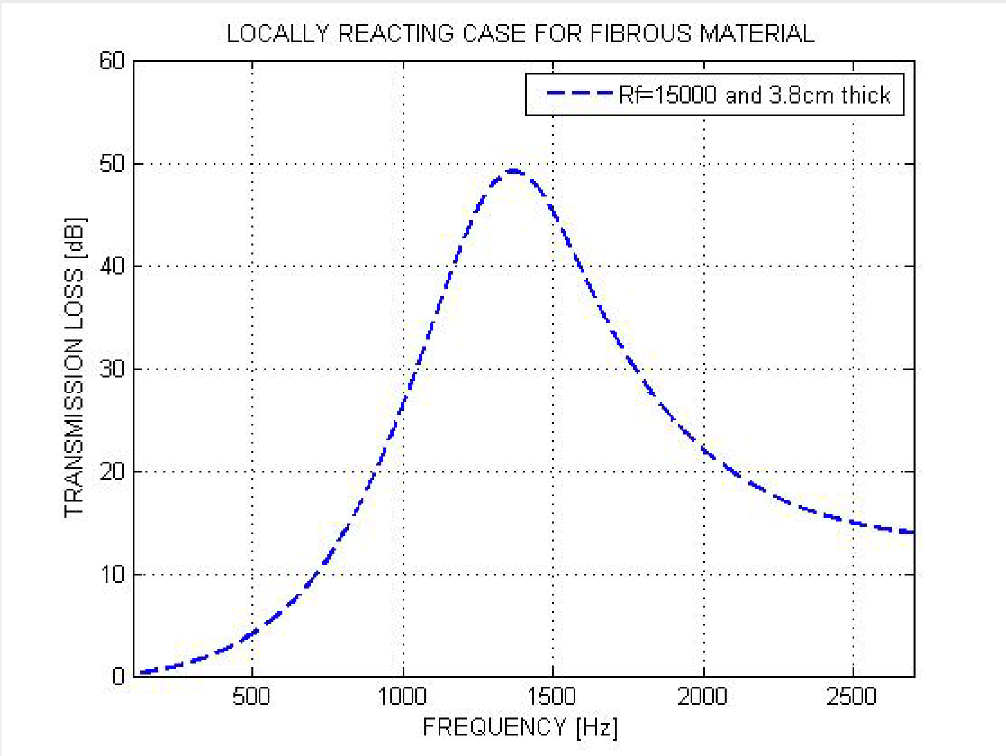
Transmission loss in a duct

$$TL = 8.685\alpha L_{tube}$$

L_{tube} : Length of a cavity (tube)

Analytical model approaches

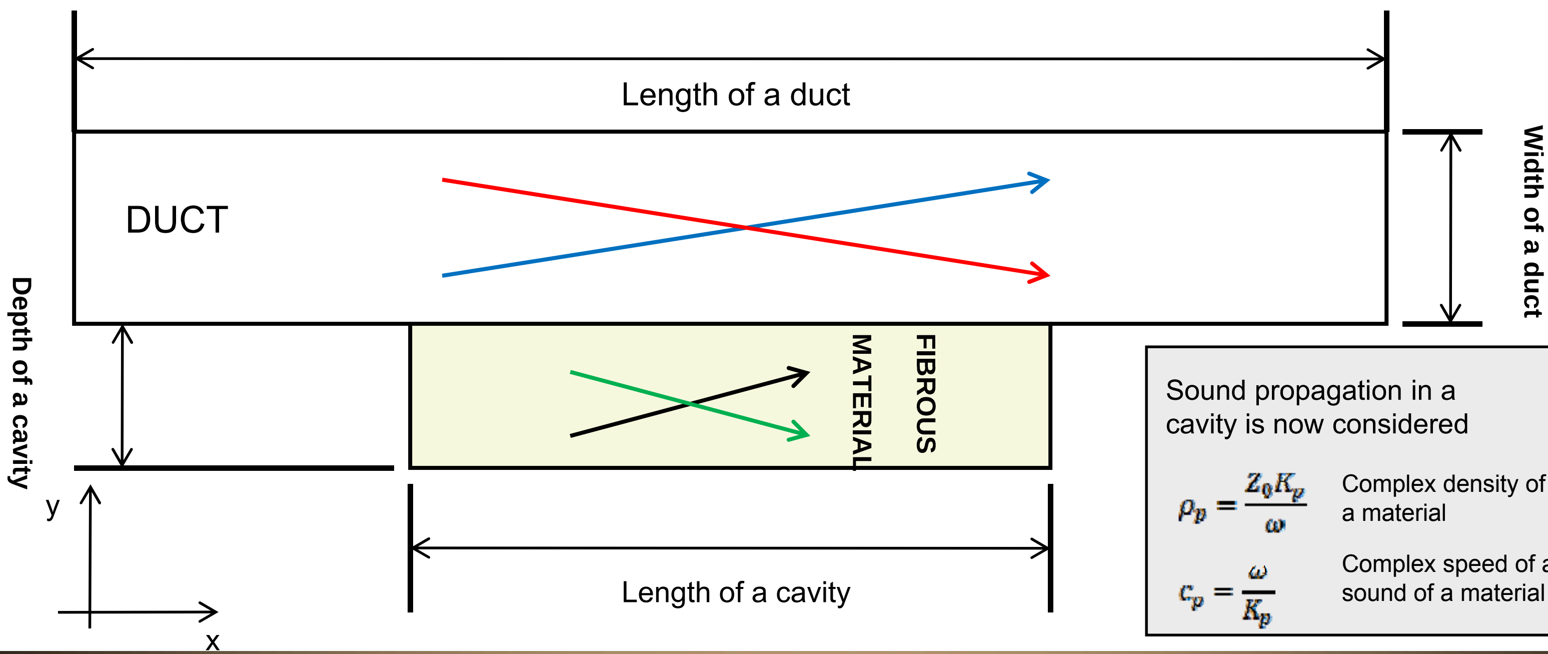
- Sound attenuation



Imaginary part of wave number determines the magnitude of sound attenuation

Analytical model approaches

- Extended reaction treatment for fibrous material
  - Miki Model is also applied to calculate characteristic impedance and propagation constant



Sound propagation in a cavity is now considered

$$\rho_p = \frac{Z_0 K_p}{\omega}$$ Complex density of a material

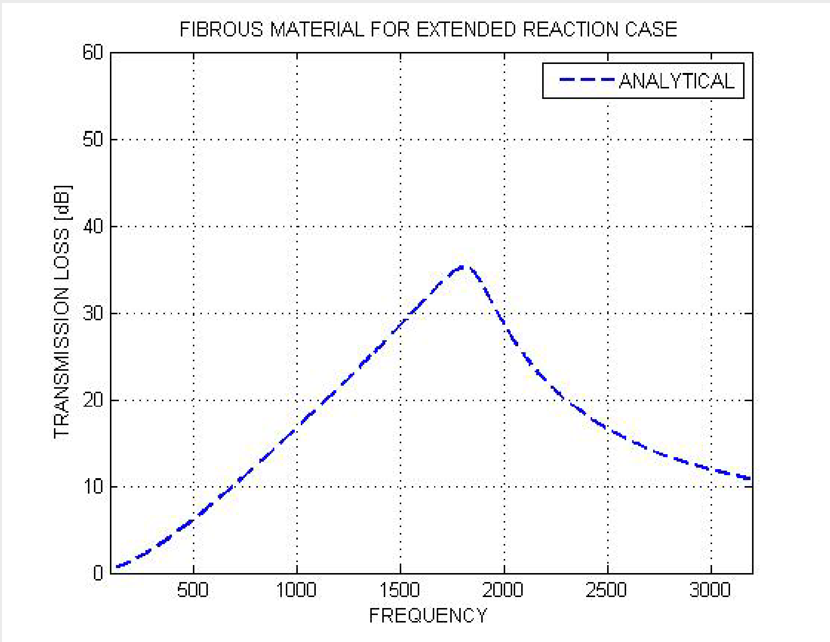
$$c_p = \frac{\omega}{K_p}$$ Complex speed of a sound of a material

Analytical model approaches

◆ Sound attenuation

Transmission loss in a duct

$$TL = 8.685\alpha L_{tube}$$



- Peak location shifted to higher frequency
- Overall sound attenuation level decreased

Analytical model approaches

- Local reaction treatment for microperforated material
  - Maa-flex Model

Transfer Impedance

$$Z = \frac{P_1 - P_2}{v_{y1}} = \frac{R_{tm}\Omega_s(1-\Omega_s)(j\omega m - j\omega\rho_o(t+2\delta)) + j\omega\rho_o(t+2\delta)\{j\omega m(1-\Omega_s) + R_{tm}\Omega_s\}}{\Omega_s(1-\Omega_s)(R_{tm} + j\omega m) + (1-\Omega_s)^2\rho_o(t+2\delta)j\omega + \Omega_s^{\,2}R_{tm}}$$

Dynamic macroscopic flow resistance

$$R_{tm} = \frac{32\eta t}{\sigma\rho_o c d^2}\left[\sqrt{1+\frac{x^2}{32}} + \sqrt{\frac{2xd}{8t}}\right]$$

End correction factor

$$\delta = \frac{1}{2}\left\{\frac{t}{\sqrt{9+\frac{x^2}{2}}} + 0.85d\right\}$$

v_{y1} : Tangential particle velocity on the panel

Ω_s : Surface porosity

m : mass per unit area

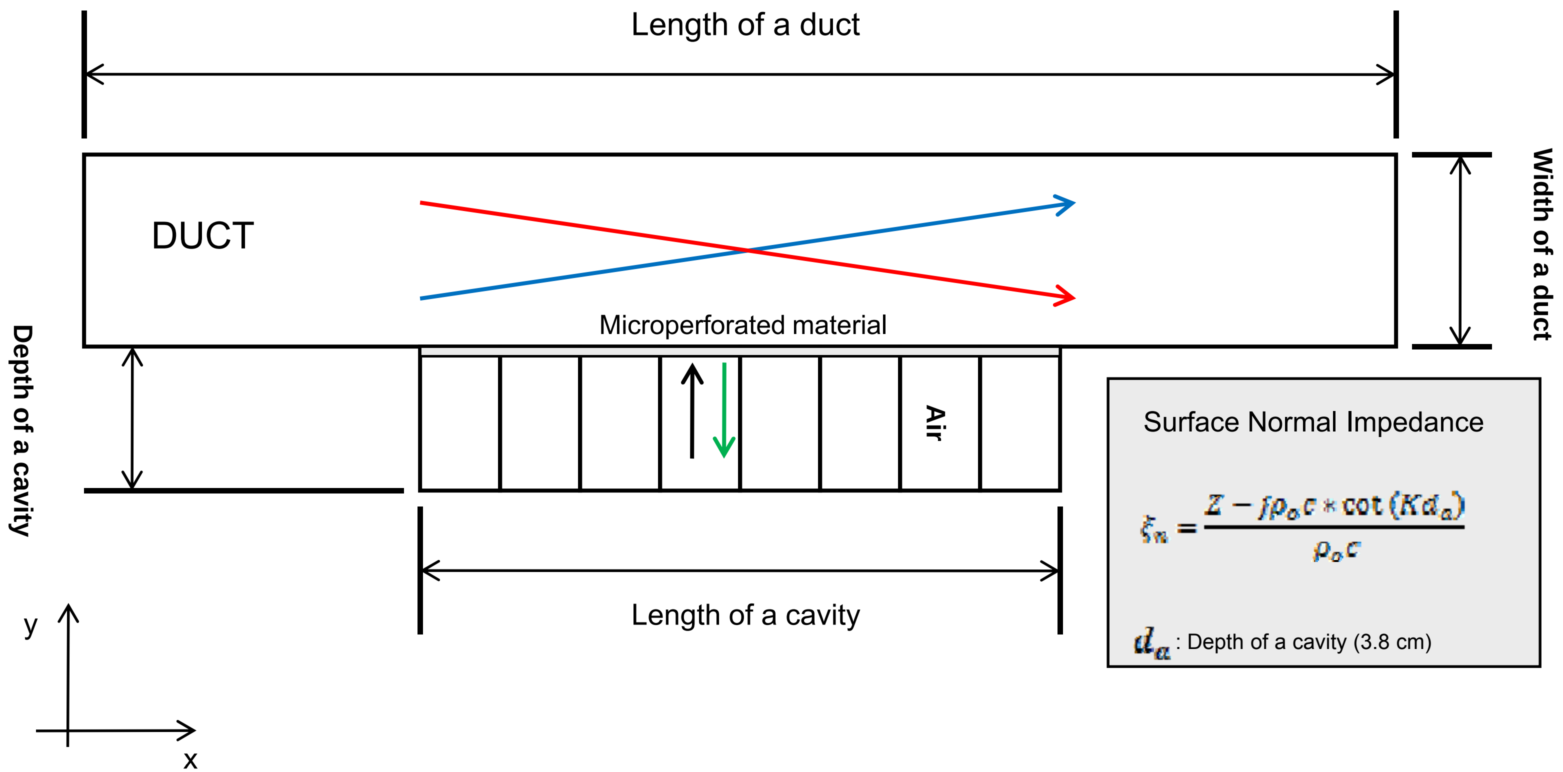
t : Thickness of the panel

ω : Tangential particle velocity on the panel

d : Diameter of holes

Analytical model approaches

◆ Configuration of local reaction treatment



Surface Normal Impedance

$$\xi_n = \frac{Z - j\rho_o c * \cot(Kd_a)}{\rho_o c}$$

d_a : Depth of a cavity (3.8 cm)

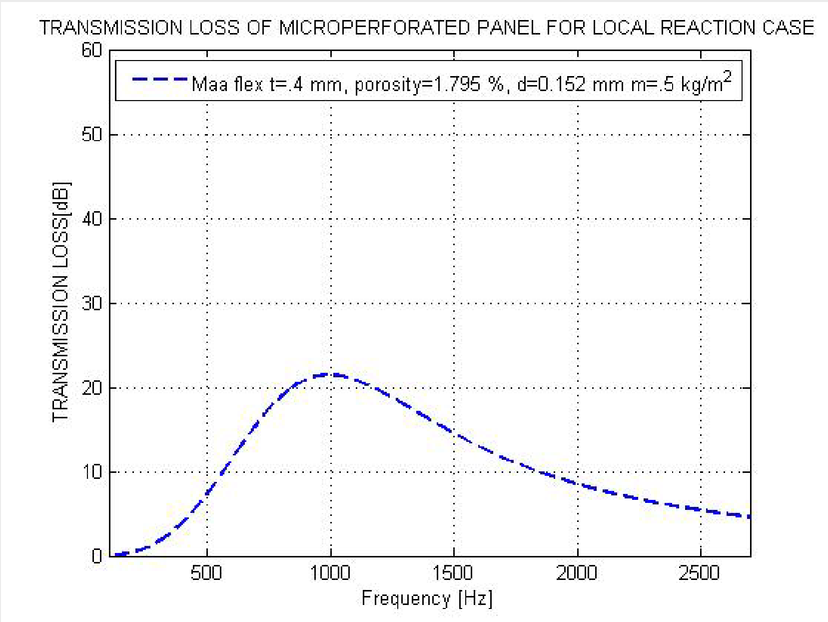
Analytical model approaches

- Sound attenuation

Transmission loss in a duct

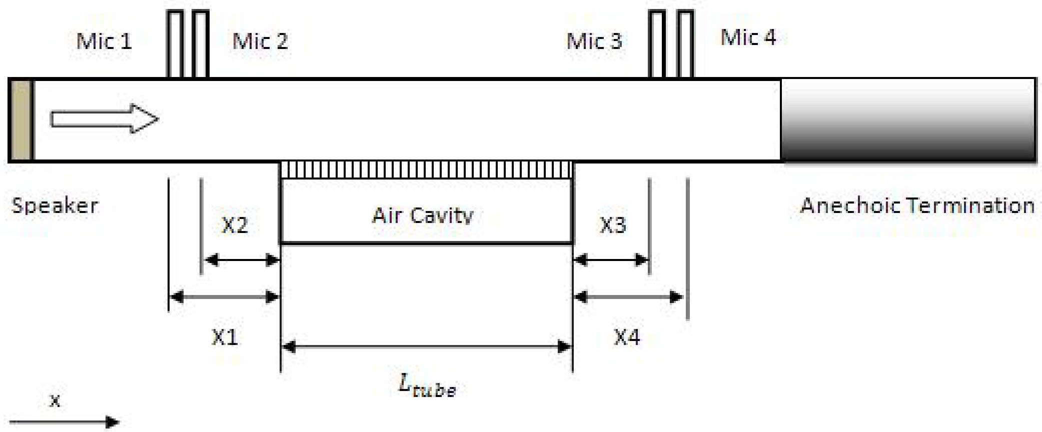
$$TL = 8.685\alpha L_{tube}$$

L_{tube} : Length of a cavity (panel)



Measurements

- 4-microphone measurements
- Duct-shaped standing wave tube
  - Configuration

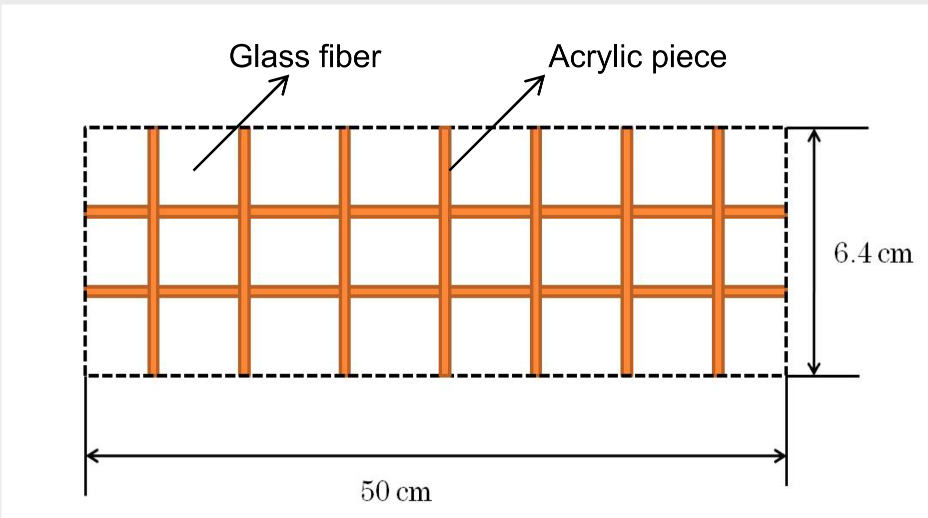


- Transfer matrix method

Measurements

◆ Local reaction treatment for fibrous material

- Yellow glass fiber
- 3.8 cm thickness
- Cavity is segmented using 2 mm acrylic pieces

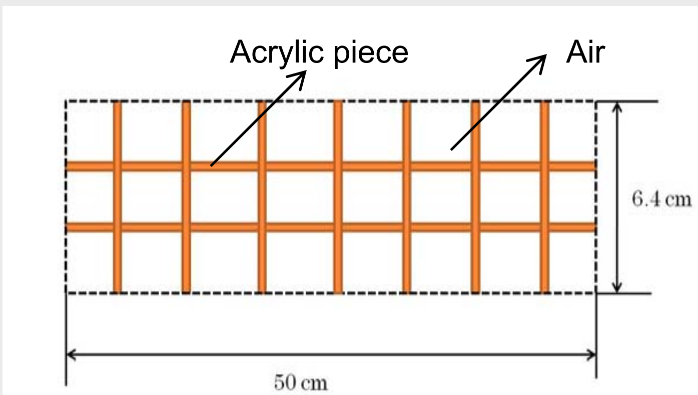


Measurements

- Local and extended reaction treatment for Microperforated materials

• Cavity is segmented using 2 mm acrylic pieces

Locally reacting case



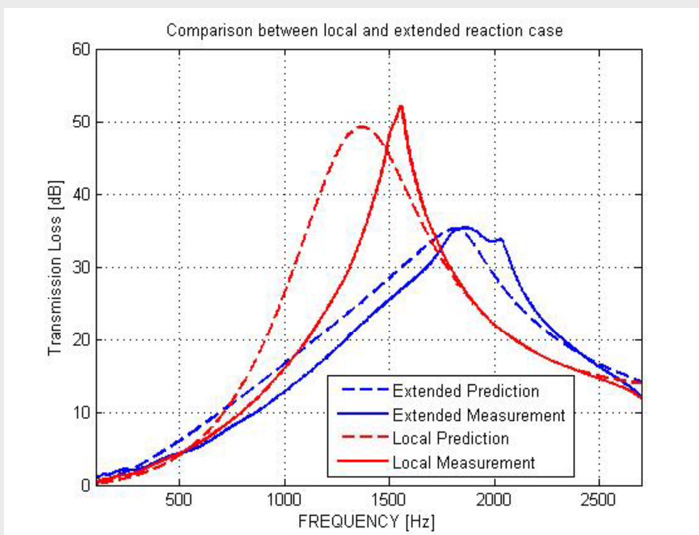
Extended reaction case

Acrylic pieces are all removed
for the extended reaction case

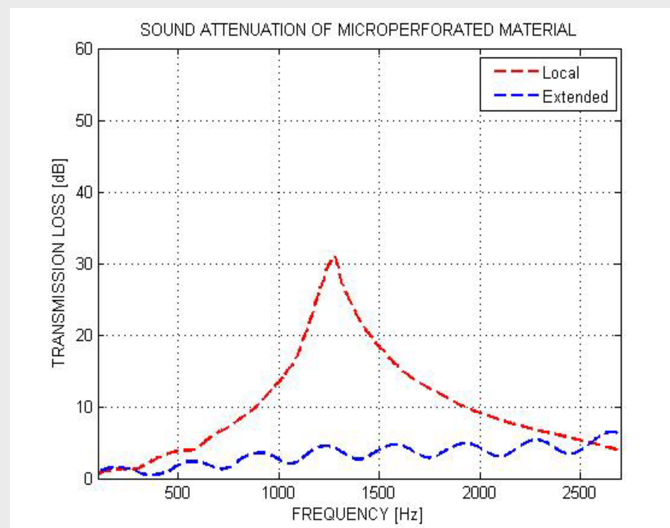
Measurements

- Local and extended reaction treatments

Glass fiber

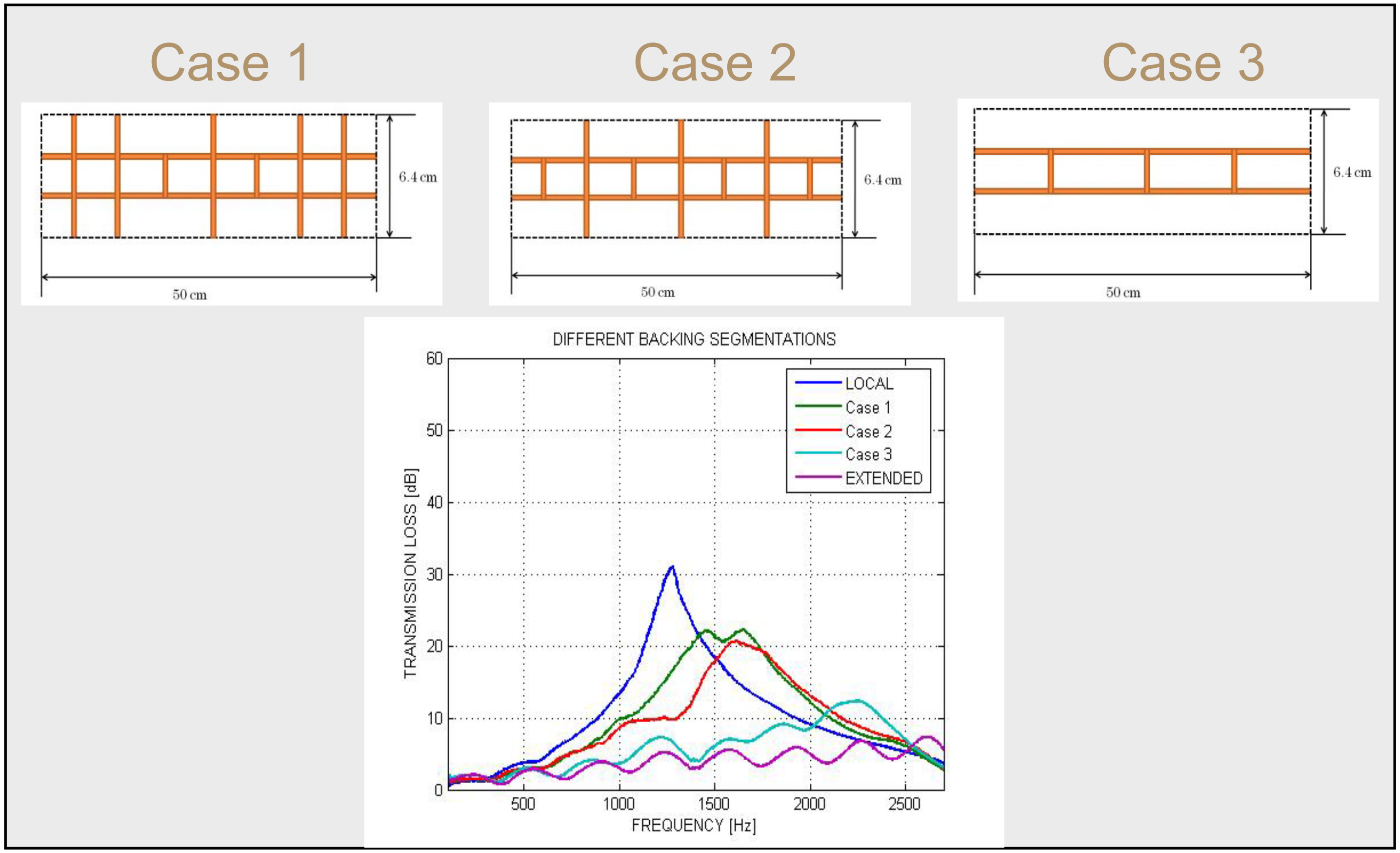


Microperforated material



Measurements

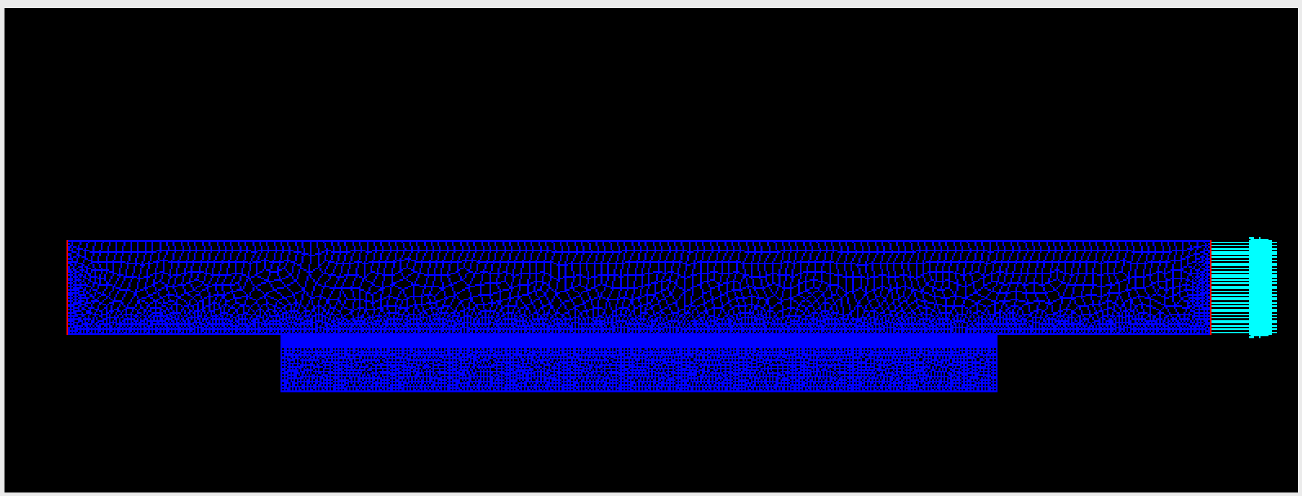
- Effects of segmentations in the cavity- microperforated



Finite element model approaches

- COMET/VISION is based on finite element implementation of the Biot theory for wave propagation in porous material
- PATRAN is used as a meshing tool

Finite element model configuration



Finite element model approaches

- Modeling microperforated as a rigid porous material
  - Attala and Sgard model is explicitly used to model

Flow resistivity $\varphi = \frac{8\eta}{\sigma r^2}$ Tortuosity $\alpha_\infty = 1 + \frac{\varepsilon_e}{t}$

Correction length $\varepsilon_e = 0.48\sqrt{\pi r^2}(1 - 1.4\sqrt{\varphi})$

Surface impedance with a finite-depth air cavity

$$Z_A = \left(\frac{2t}{r} + 4\right)\frac{R_s}{\varphi} + \frac{1}{\varphi}(2\varepsilon_e + d)j\omega\rho_o - j\rho_o c_o \cot(k_o L)$$

$$R_s = \frac{1}{2}\sqrt{2\eta\omega\rho_o}$$

Viscous and thermal characteristic lengths $\Lambda = \Lambda' = r$

η : dynamic viscosity σ : porosity r : radius t : thickness

Finite element model approaches

- Local and extended reaction treatments

- Glass fiber is modeled as an elastic solid

Parameters	Value
Porosity (%)	9.90e1
Flow resistivity (Rayls)	1.500e4
Tortuosity	1.00
Thermal Characteristic Length (m)	1.00e-4
Viscous Characteristic Length (m)	5.00e-4
Densisty (kg/m^3)	6.88
Young's modulus	1.00e3
Loss Factor	0.200
Poisson's Ratio	0.010

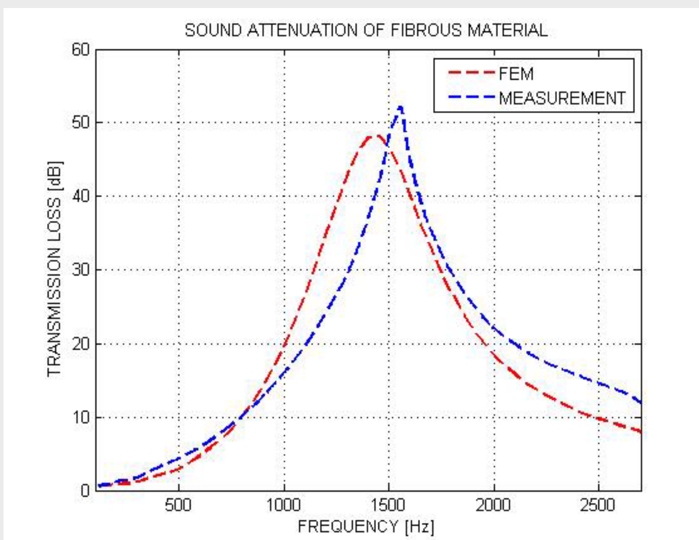
- Microperforated material as a rigid porous material

Parameters of Micro-perforated panel	Thickness (m)	Porosity (%)	Hole diameter(m)	Length (m)	Mass per unit area(kg/m^2)
	0.0004	1.8	0.0000152	0.5	0.5

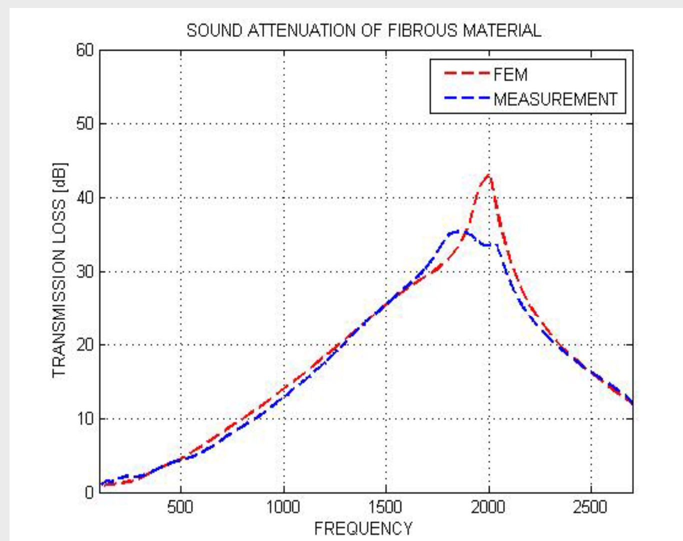
Finite element model approaches

- Local and extended reaction treatments for fibrous material

Local reaction case



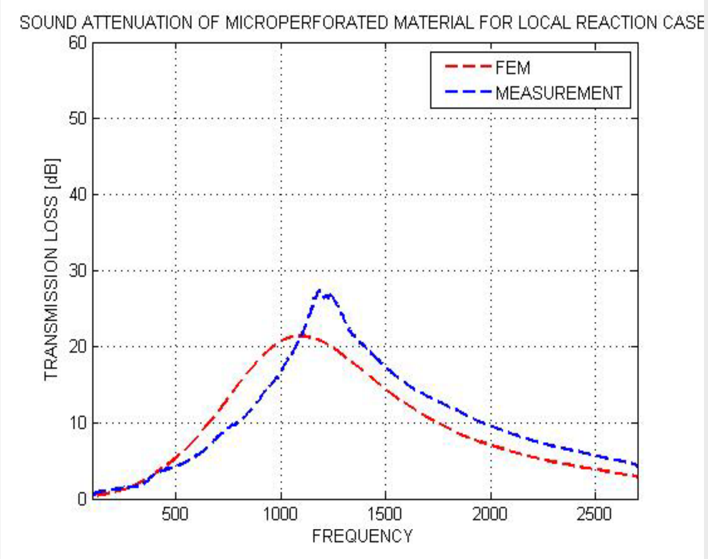
Extended reaction case



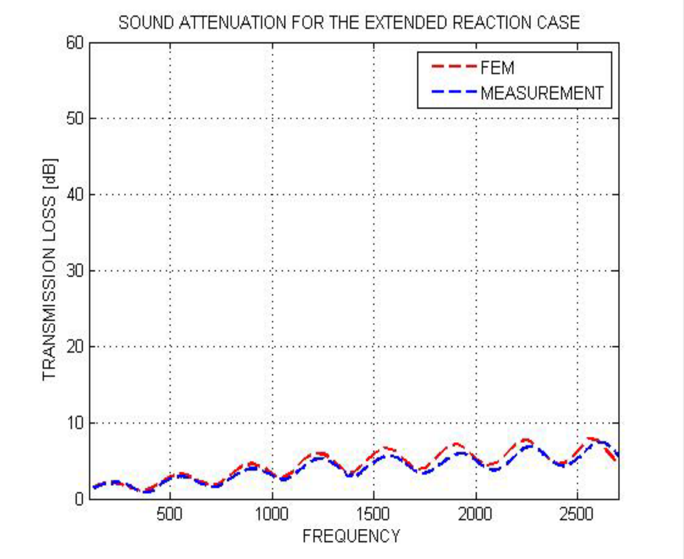
Finite element model approaches

- Local and extended reaction treatments for microperforated material

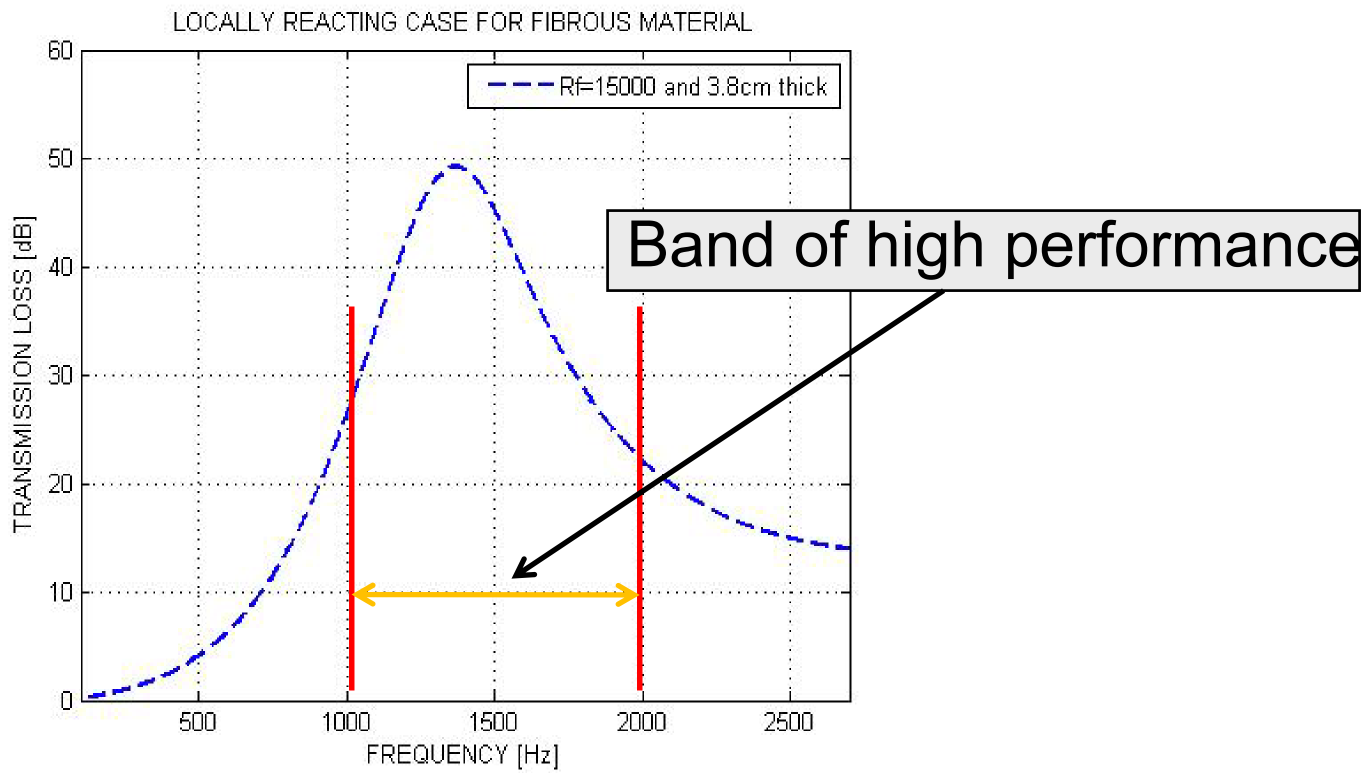
Local reaction case



Extended reaction case



Matching fibrous performance

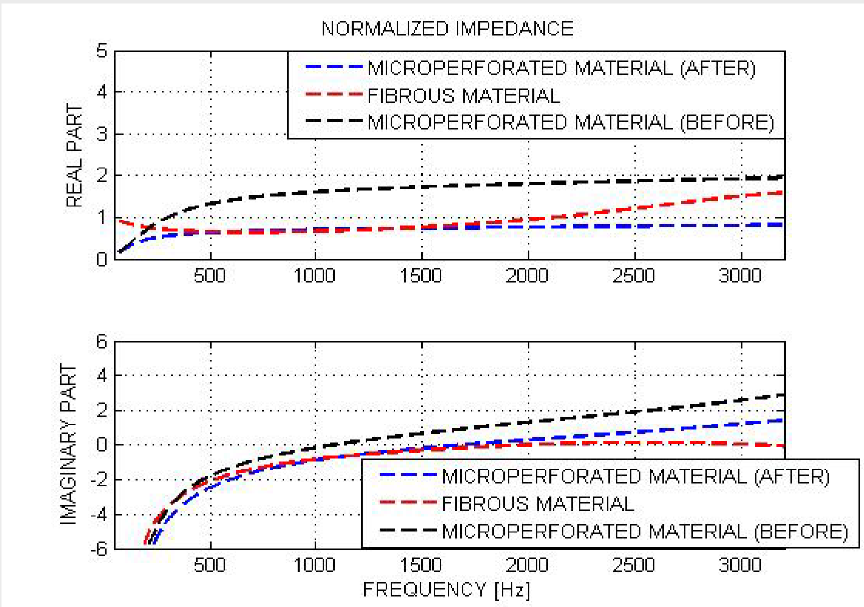


- To match TL performance, create microperforated treatment having same surface normal impedance as fibrous layer in high performance band

Comparisons

- Microperforated material matching acoustical performance of fibrous material

NORMALIZED IMPEDANCE



- 3.8 cm air backing depth for microperforated material
- 3.8 cm thick fibrous material

- Least square error method is applied to match the both real and imaginary part of fibrous material by adjusting the parameters of microperforated material.

Comparisons

- Parameters of microperforated material

•Before adjustment

Parameters of Micro-perforated panel	Thickness (m)	Porosity (%)	Hole diameter(m)	Length (m)	Mass per unit area(kg/m^2)
	0.0004	1.8	0.000152	0.5	0.5

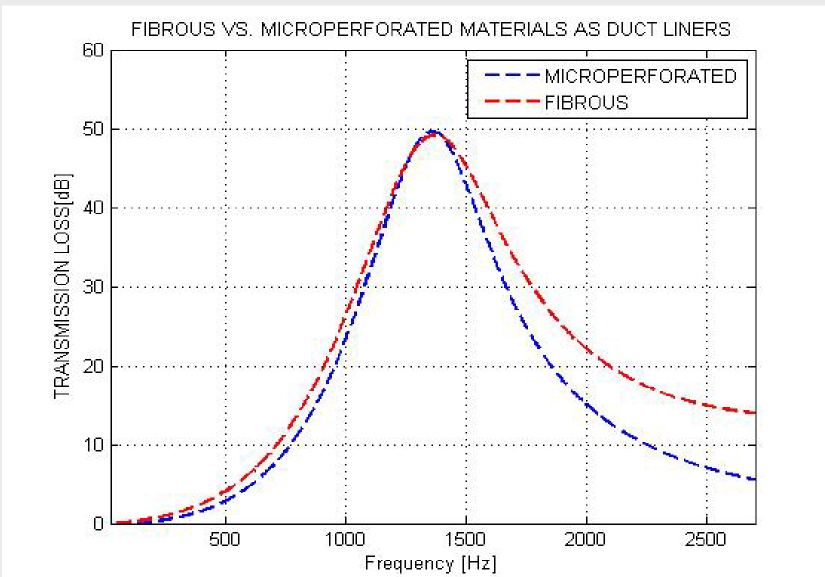
•After adjustment

Parameters of Micro-perforated panel	Thickness (m)	Porosity (%)	Hole diameter(m)	Length (m)	Mass per unit area(kg/m^2)
	0.0004	5.6	0.000135	0.5	0.365

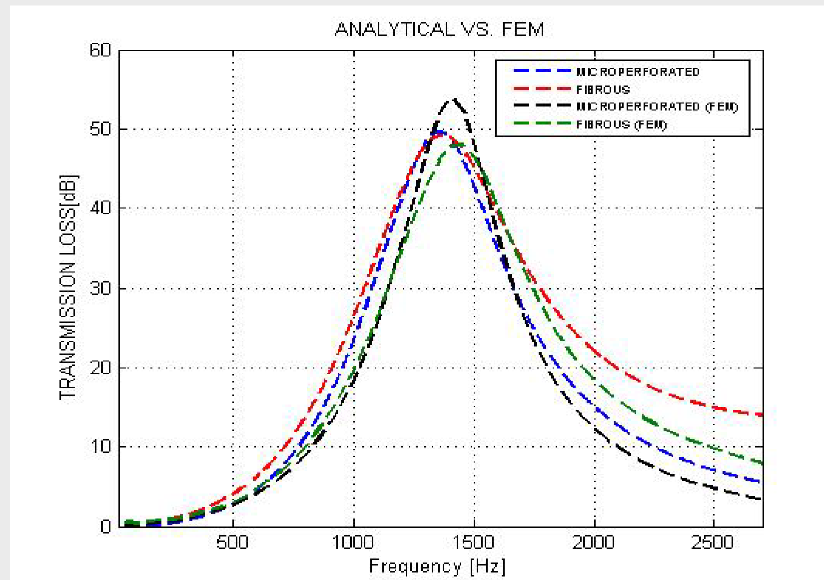
Comparisons

◆ Transmission loss of duct linings

Local reaction treatment
(Analytical approach)



Local reaction treatment
(Finite element approach)



Conclusions

◆Analytical predictions provided the reasonable agreement with measurements.

◆Microperforated material was successfully modeled as a rigid porous material with equivalent tortuosity.

◆Finite element model used in this study was appropriate.

◆Desired parameters of microperforated material were obtained to match the impedance of the fibrous material.

◆Microperforated duct liner emulated comparable acoustical performance of fibrous material duct liner

◆Microperforated duct liner could be used as an alternative absorbing lining whenever fibrous duct lining is not desired